RESPONSE OF BLUE HUCKLEBERRY TO PRESCRIBED FIRES IN A WESTERN MONTANA LARCH-FIR FOREST

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RESEARCH SUMMARY

In a western larch/Douglas-fir forest type in western Montana, 9 spring and 11 fall understory burns were conducted. Multiple regression equations related the number of Vaccinium globulare (blue huckleberry) stems present 1 and 2 years after fire to the number present before fire, prefire fuel loadings, moisture content of fuel, duff and soil, environmental conditions, fuel reduction, fire intensity, and temperatures reached at duff and soil surfaces during the fires. Postfire Vaccinium numbers were most closely related to the number of Vaccinium present before fire. The number of sprouts depended upon the fire treatment received by stems and rhizomes. There was no evidence of any seasonal variation in the physiological ability of Vaccinium to produce sprouts.

In the spring, mostly fine fuels burned; in the fall, dry large fuels and duff layers often burned. All spring fires increased Vaccinium stem numbers. Plants were pruned but high duff and soil moisture protected rhizomes from heat. Many more rhizomes were killed during fall fires than spring fires. Soil moisture was too low to protect rhizomes from the great amounts of heat released.

INTRODUCTION

Many species of shrubs common to western forests respond to fire by reproducing vegetatively. After fire has killed the top of the plant, sprouts develop from root crowns or from rhizomes, underground stems located in duff and soil layers (fig. 1).

Vegetatively reproducing shrubs are among the first species to recolonize an area after fire. New growth provides forage and often bears increased fruit crops. Cover is provided for small wildlife species. Lush vegetation can protect the soil surface from splash erosion, but can also offer severe competition to new tree seedlings. An interlacing network of *Vaccinium* rhizomes and roots can be very effective in preventing water and wind erosion on slopes (O'Rourke 1942), a function that would be particularly important on a site where aboveground vegetation had been temporarily removed by fire. Because rhizomes store and translocate nutrients absorbed by their adventitious roots (Trevett 1956b), a living rhizome system can be very important in retaining nutrients released by fire.

Vaccinium globulare (blue huckleberry), *V. membranaceum* (mountain huckleberry) (Minore 1975), *Symphoricarpos albus* (snowberry), and *Spiraea betulifolia* (white spiraea) sprout after fire from dormant buds located on rhizomes. The amount of shrub sprouting may vary widely after fires in different locations or seasons, and within the area of a single fire. Specific factors that account for these differences have not been identified.

An increased use of prescribed fire is being considered by forest managers to reduce understory fuels, thin stands, and manipulate wildlife habitat. Managers must execute burns under specified burning conditions to achieve desired objectives. We have not known whether a specific relationship exists among burning conditions, fire characteristics, and shrub response. The important role that shrubs play in determining postfire site quality demands that they be taken into account when planning prescribed burning.

Figure 1.--Rhizome section of Vaccinium globulare. *Arrows indicate location of several dormant buds.*

Background

A study was developed at the Northern Forest Fire Laboratory of the USDA Forest Service to obtain criteria for scheduling prescribed fires to obtain desired levels of understory fuels (Norum 1975). Twenty understory burns were conducted in Douglas-fir/western larch stands from May 11 to June 29, and September 11 to October 11, 1973. Plots averaged one-third acre. Strip headfires were ignited at 5-meter intervals with drip torches.

Fuels were sampled before and after fire. Downed woody fuels were inventoried by the planar intersect method (Brown 1975). Herbaceous biomass and duff depth were measured. Shrub stems were counted to predict shrub biomass (Brown 1976). Moisture content as a percent of ovendry weight was determined for samples of fuel, duff, and the top 5 cm of soil collected just before plot ignition. Asbestos plates with stripes of temperature-sensitive paint monitored duff and soil heating to depths of 15 cm (5.9 inches). Fuel loadings, fuel and duff moisture contents, and environmental parameters were statistically related to fuel reduction, fire intensity, soil temperatures attained during burning, small-stem mortality, and percentage of cambial kill of trees greater than 5 inches d.b.h. (Norum 1975).

Objectives

A study was undertaken to determine whether fuel loading, burning conditions, or fire effects could be related to differences in shrub response (Miller 1976). This report is based upon that study.

Study objectives, as modified, were to:

1. Relate the number of *Vaccinium globulare* stems on the burn plots 1 and 2 years after fire to:

    a. Preburn conditions

        - fuel loading
        - number of *Vaccinium* stems

    b. Season of burn

    c. Burning conditions

        - atmospheric conditions
        - dead woody fuel moisture
        - duff and soil moisture

    d. Fire effects

        - fuel reduction
        - fire intensity
        - duff and soil heating

2. Identify factors that promoted or inhibited *Vaccinium* sprouting. If firm relationships were established, formulate guidelines for *Vaccinium* management by means of understory burning.

LITERATURE REVIEW

Heat Transfer in Soil

Wijk (1963, in Smith 1966b) has stated that heat is transferred through soil largely by conduction. Wet soil is a better conductor of heat than dry soil. However, wet soil is heated more slowly than dry soil because water requires more heat energy than a solid to raise its temperature an equivalent amount.

Albini (personal communication 1975, Northern Forest Fire Laboratory) has said that the principal method of heat transfer through a porous medium such as duff or soil is vapor transfer. Water in duff layers is evaporated by fire, absorbing about 540 cal/g of heat in the process. The vapor moves in all directions in response to the vapor pressure gradient. Some steam will move downward through the profile in macropore spaces, condensing on cool surfaces if the relative humidity is near 100 percent. The latent heat absorbed during evaporation will be released as vapor condenses. If duff and soil are dry, heat will be directly transferred to the particles. If water is present, the latent heat will be expended in heating the water. Only a very small amount of heat would be transmitted to duff and soil particles with a film of water above them. Uggla (1973) has described a "sweating zone" immediately below the fire surface in thick moist humus, the result of condensation of fire evaporated moisture on the cold humus surface.

According to Albini (personal communication 1975, Northern Forest Fire Laboratory), this layer will insulate layers below from further heat penetration until it is completely evaporated by fire heat. Moist soil layers may also retard heat penetration by deflecting additional steam back toward the surface. The amount of deflection may be related to the amount of water in soil macropore space. Duff and soil moisture are thus important regulators of heat penetration into the forest floor.

Shearer (1975) found that root mortality in nonconiferous species resulting from slash burns in Douglas-fir/western larch varied according to the interaction between fire heat and soil water. Maximum soil temperatures occurred on microsites with high fuel concentrations, low soil moisture, or both. When soil moisture content averaged 20 percent and moisture content of lower duff averaged 28 percent, considerable soil heating resulted from fires of even low intensity.

Vaccinium Response to Fire

Individual clones of *Vaccinium* have an extensive rhizome system, only a small part of which is manifested by aboveground shoots (Smith 1966a). Rhizomes of *V. angustifolium* are concentrated in the organic and surface soil layers (Trevett 1956b), while *V. membranaceum* rhizomes are generally found between 8 and 30 cm below the surface (Minore 1975). *V. globulare* rhizomes are most densely distributed in the top 10 to 15 cm of duff and soil, but have been found at depths of 25 cm below the duff surface (personal observation). Dormant buds are evenly distributed across all rhizome surfaces of these species, although they are sometimes deeply buried in tissue on thicker rhizomes.

Fields of *V. angustifolium* in eastern Canada and the northeast United States are pruned with fire to increase commercial blueberry production. Burns are conducted in fall or spring when plants are dormant and wet ground protects the rhizomes from fire (Badcock 1958). Straw is often used to carry fire. Fires need not be intense since plant tissue is killed by temperatures of 50° to 60° C (122° to 140° F) (Meyer and others 1973).

The stand thickens in response to fire pruning by producing new sprouts from the dormant buds at the base of burned stubs or from rhizomes just below the ground surface (Trevett 1956a). The buds that elongate are those few closest to where the stem or rhizome is killed. Whether pruned in the fall or in early spring, shoots emerge in May (Eaton and White 1960). Energy for growth comes from carbohydrate stored in rhizomes and roots. Stained rhizomes of *V. globulare* collected in early June and early July had abundant starch grains, except for an apparently young rhizome of small diameter that had no starch grains (personal observation).

New rhizomes are often produced in response to vigorous aerial plant growth (Kender 1967). Rhizomes initiated from buds at deep levels tend to "migrate" laterally, becoming important in extension of clonal boundaries (Trevett 1956b). Rhizomes initiated from buds near the surface tend to turn toward the surface and produce leafy shoots after emerging from the ground. The shoot tips may be stimulated to grow toward the surface by very small amounts of light, because low-intensity light has induced laterally growing rhizomes to become vegetative shoots in laboratory experiments (Barker and Collins 1963). Trevett (1956b) postulated that duff reduction by fire could result in stem development from rhizomes which had been growing laterally. This could occur if duff thinning allowed light to penetrate to rhizome tips.

The *Vaccinium* plants on a site after a fire are mixtures of unburned plants and newly regenerated plants. Seedlings of *Vaccinium* are rarely found and are not important in recolonization of burned sites after fire (Peter Stickney, personal communication 1976, Forestry Sciences Laboratory, Missoula, Montana). Some new stems may result from rhizome growth stimulated by fire. Most of the newly regenerated plants are sprouts induced by fire killing of stems and rhizomes. The postfire stand of *Vaccinium* is thus closely related to the fire treatment that plants receive.

STUDY AREA AND TREATMENT

The study area was within the University of Montana Lubrecht Experimental Forest northeast of Missoula, Montana, at an elevation of 1,460 meters (4,800 feet) m.s.l. Plots were on northwest to northeast aspects on slopes ranging from 15 to 45 percent. The sandy textured soils of the Holloway Series are thin and poorly developed with numerous quartzite argillite rocks of varying sizes (Stark 1976). The dead and down woody fuel loading on the fire plots ranged from 1.4 to 11.4 kg/m^2 (6 to 51 tons per acre). Very old partially decomposed slash from light selective harvests prior to 1930 was supplemented by considerable amounts of naturally accruing fuels (fig. 2 and 3).

Figure 2.--Fuels typical of Lubrecht Forest.

Figure 3.--Logging slash from selective cutting.

Habitat types were classified according to Forest Habitat Types of Montana (Pfister and others, review draft, 1974. Forestry Sciences Laboratory, Missoula, Montana). The area is predominantly in the *Pseudotsuga menziesii-Vaccinium globulare* habitat type, *Arctostaphylos uva-ursi* phase, with certain plots transitional to the *Pseudotsuga menziesii-Xerophyllum tenax* habitat type, *Arctostaphylos uva-ursi* phase. The overstory is a fully stocked stand of all-aged Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) (taxonomic nomenclature for Lubrecht species follows Hitchcock and Cronquist 1973), western larch (*Larix occidentalis* Nutt.), lodgepole pine (*Pinus contorta* Dougl.), and an occasional ponderosa pine (*Pinus ponderosa* Laws.). The undisturbed shrub understory is dominated by blue huckleberry (*Vaccinium globulare* Rydb.) or white spiraea (*Spiraea betulifolia* Pall. var. *lucida* Dougl.), or both; or blue huckleberry and menziesia (*Menziesia ferruginea* Smith), with occasional snowberry (*Symphoricarpos albus* (L.) Blake), willow (*Salix scouleriana* Barratt), rose (*Rosa* spp.), and serviceberry (*Amelanchier alnifolia* Nutt.) (fig. 4 and 5).

The number of *Vaccinium* stems, fuel loading, and atmospheric conditions were similar between spring and fall burned plots at the time of their ignition. Fuel, duff, soil, and understory foliage moisture content varied considerably between the two burning seasons. Measured fuel, duff, soil, and foliar moisture content are indicated in figure 6. Figure 7 shows a theoretical curve for large fuel moisture content based upon an analysis by Brackebusch (1975).

Figure 4.--Most forest openings contained dense stands of Vaccinium globulare.

Figure 5.--Typical Vaccinium*--fuel association.*

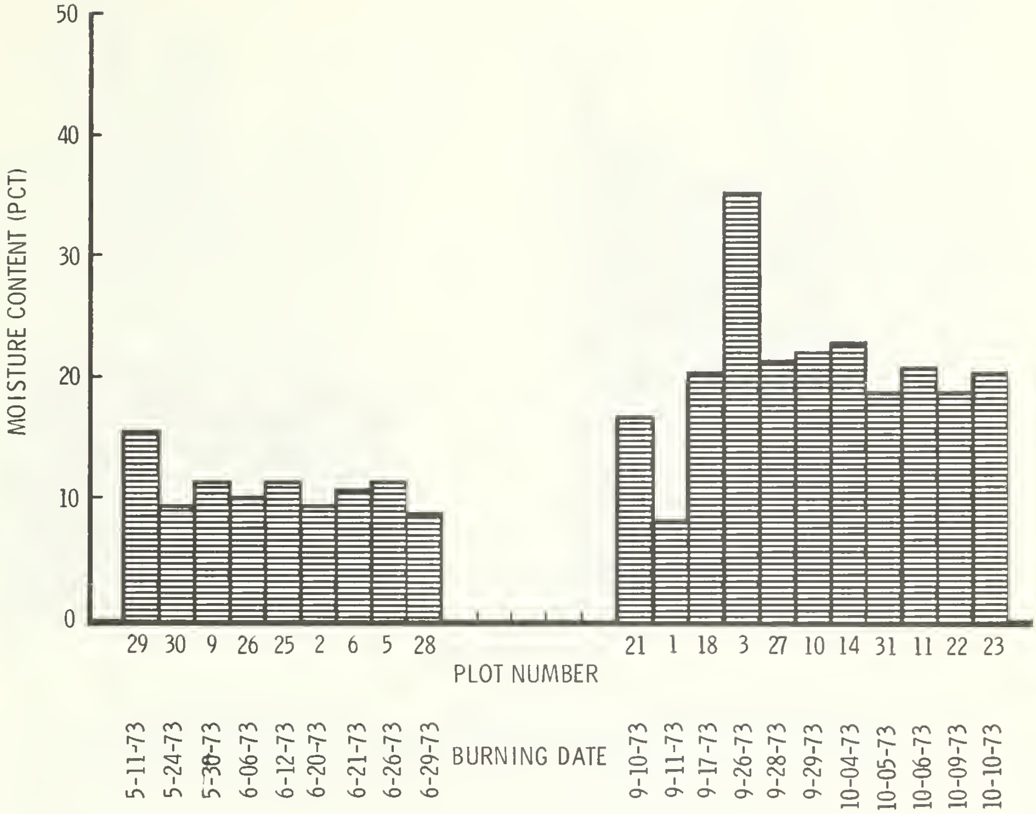

Figure 6a.--0 to 0.635 cm (0 to 1/4 inch) diameter fuel moisture content.

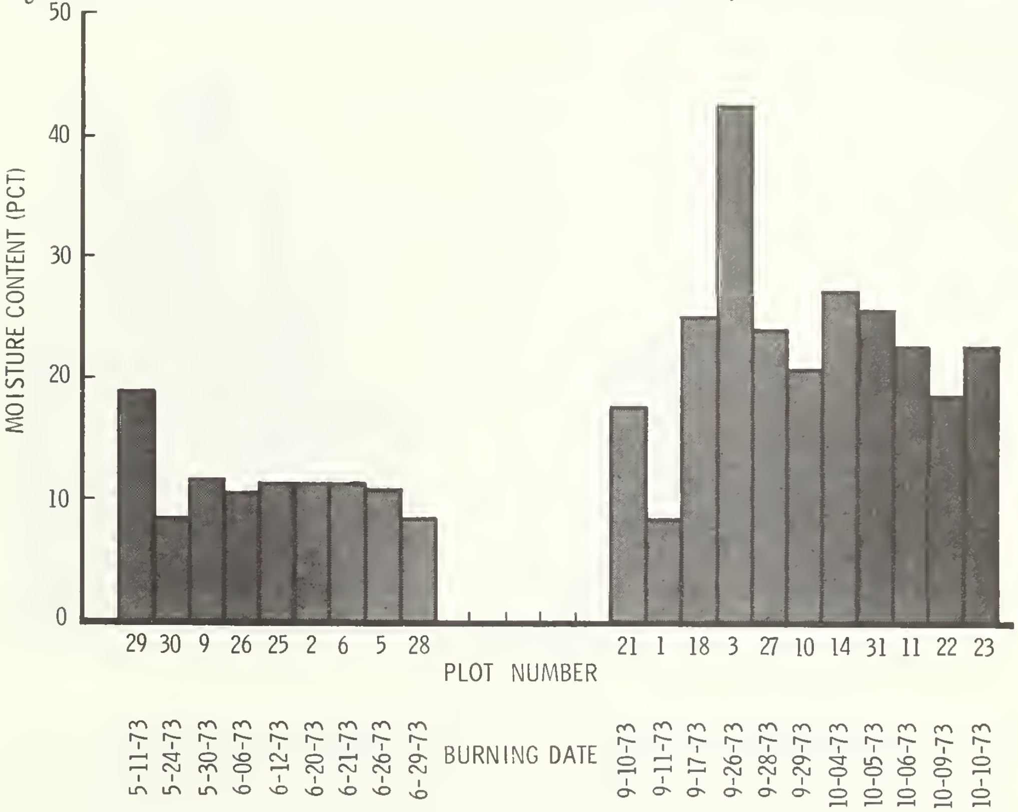

Figure 6b.--0.635 to 2.54 cm (1/4 to 1 inch) diameter fuel moisture content.

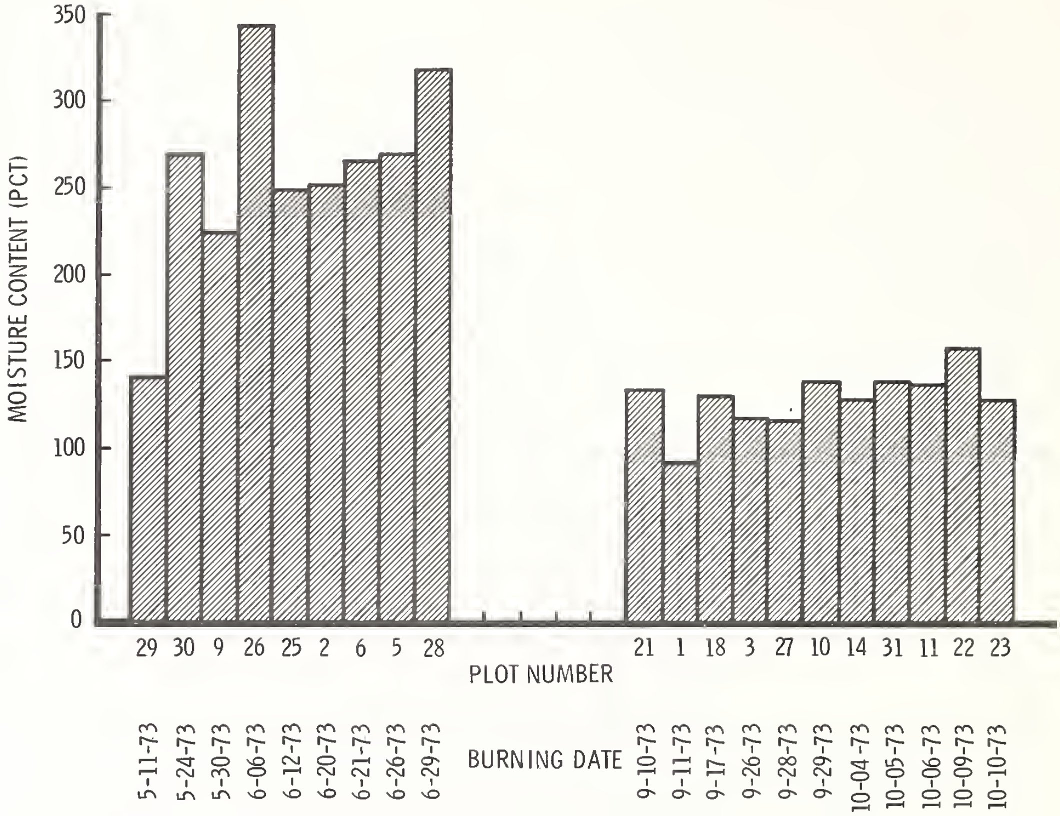

Figure 6c.--Understory foliage moisture content (percentage).

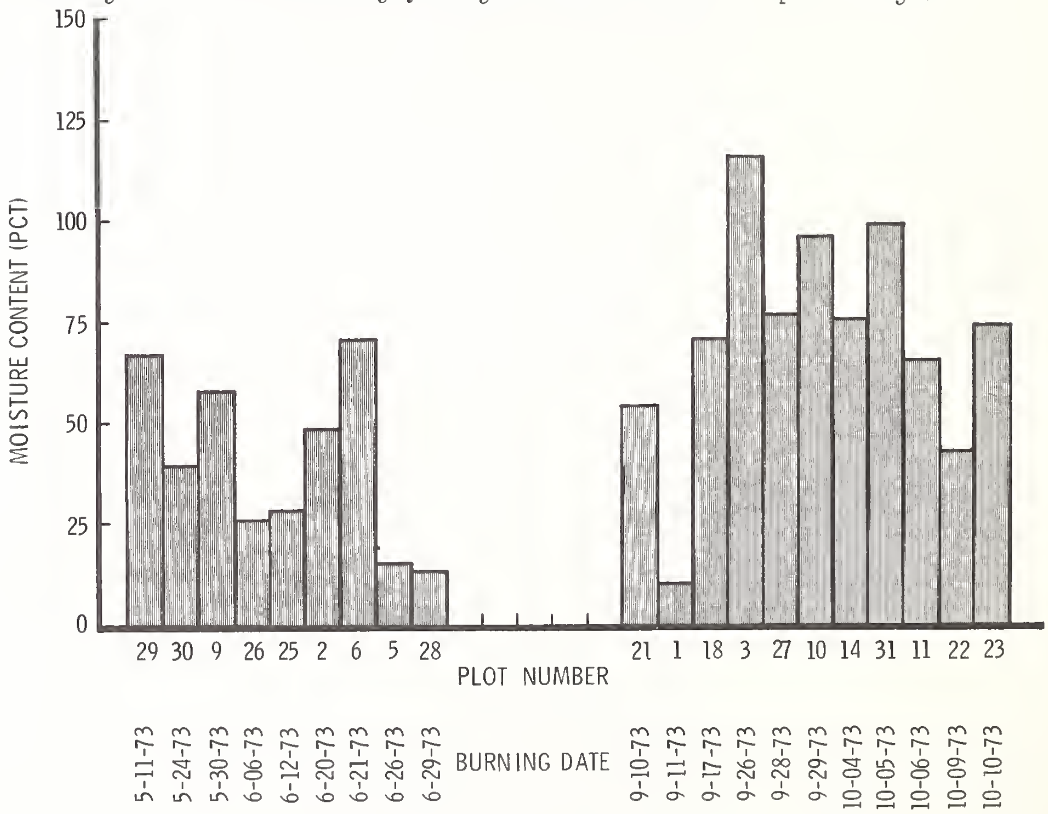

Figure 6d.--Moisture content of upper duff (percentage).

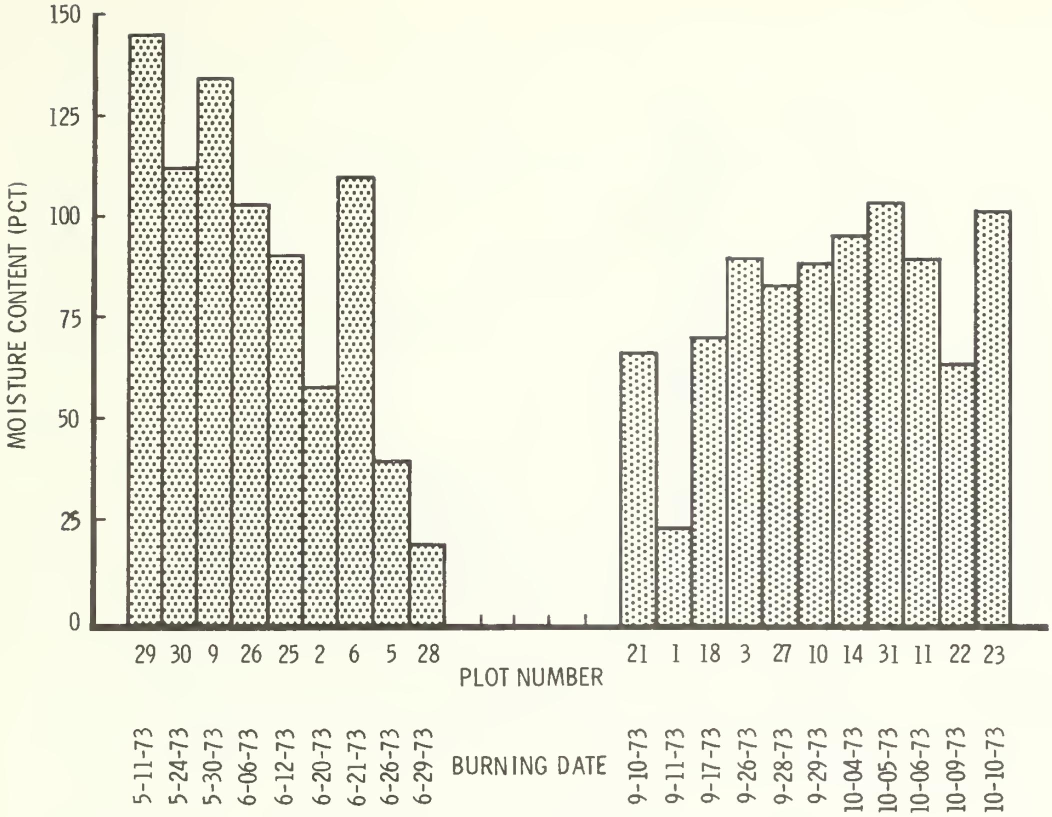

Figure 6e.--Moisture content of lower duff (percentage).

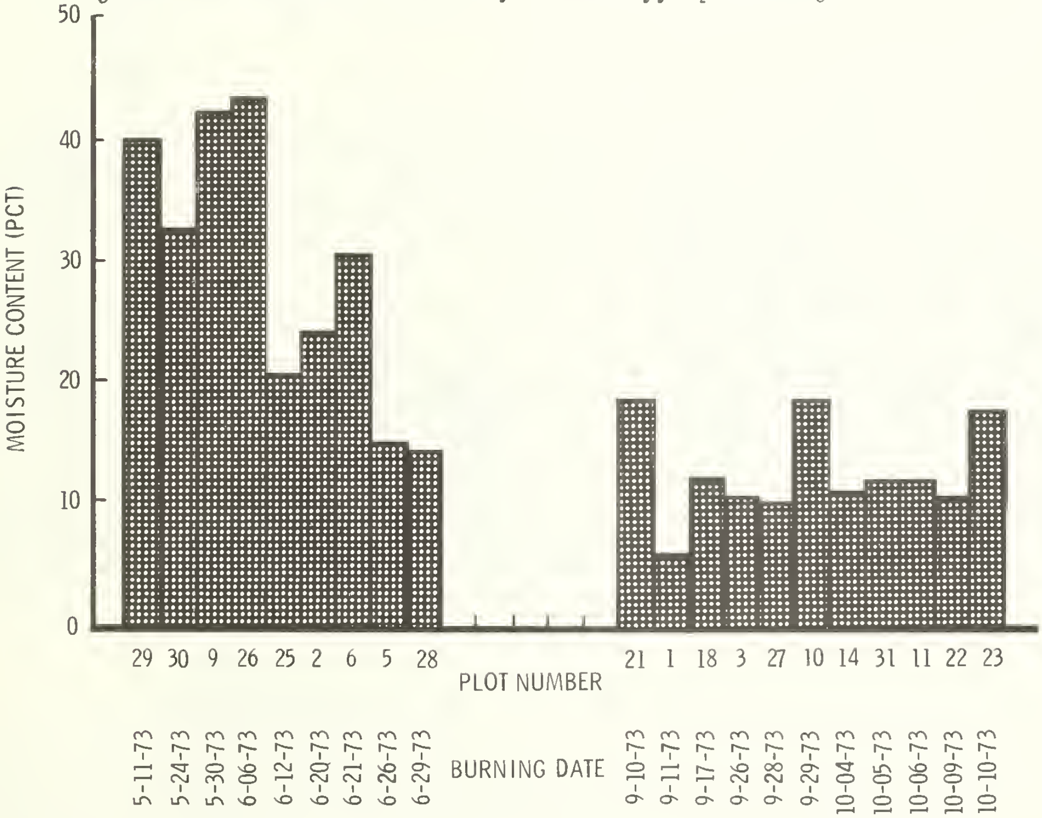

Figure 6f.--Moisture content of the top 5.0 cm of soil (percentage).

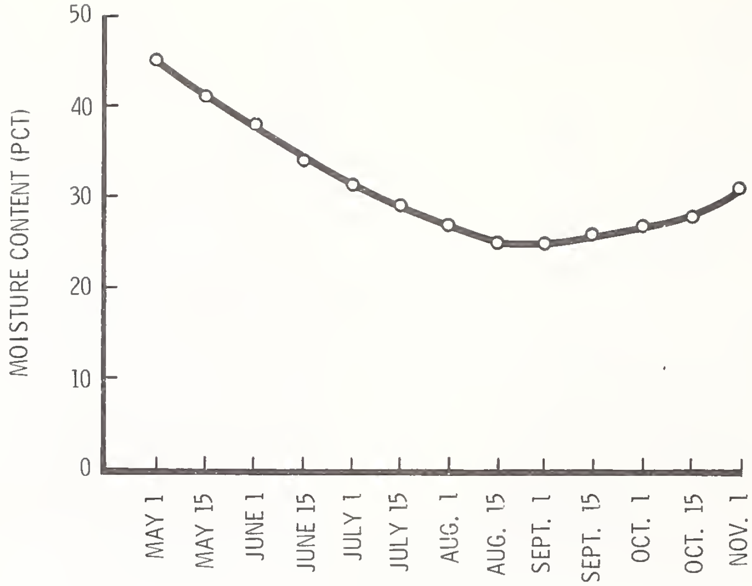

Figure 7.--Moisture content of large sound fuels (percentage).

Moisture content of understory foliage was high in the spring because of the flush of new growth. Fuel, duff, and soil moisture decreased throughout the spring. Fall rains raised the moisture content of fine fuels and duff but apparently did not soak through to soil layers. Large fuels were still dry in the fall season (Rodney A. Norum personal communication, 1976, Northern Forest Fire Laboratory).

Fire effects varied between seasons. Spring fires were more intense in terms of maximum energy output per unit time, as calculated according to Van Wagner's formula relating fire intensity to crown scorch height (Norum 1975). However, fall fires produced larger amounts of total heat, caused greater duff and soil heating, and led to more complete combustion of fuels and duff than occurred in the earlier burning season.

Duff drying and consumption were promoted by the burning of associated fuels (Norum 1975). Burning duff contributed to heating of adjacent duff and soil layers. (Frank A. Albini, personal communication 1976, Northern Forest Fire Laboratory). Duff depth reduction and average mineral soil surface temperature, indicated for each plot in figure 8, describe the differences in the subsurface heat regime.

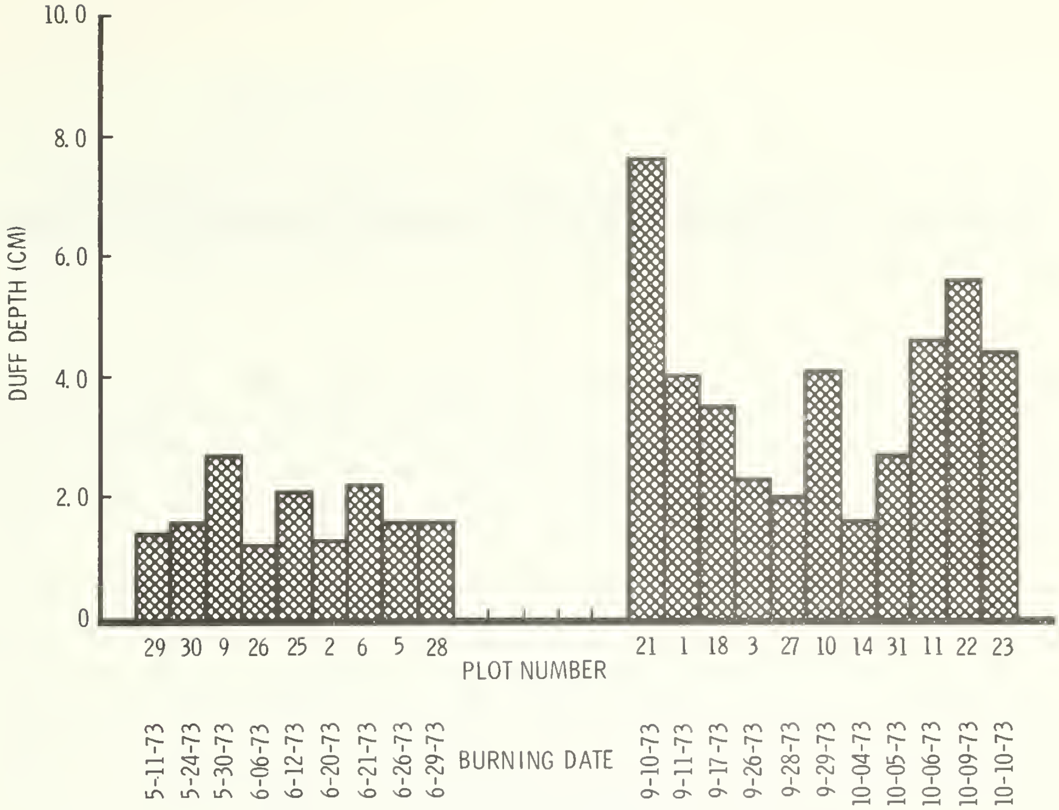

Figure 8a.--Duff depth reduction (cm).

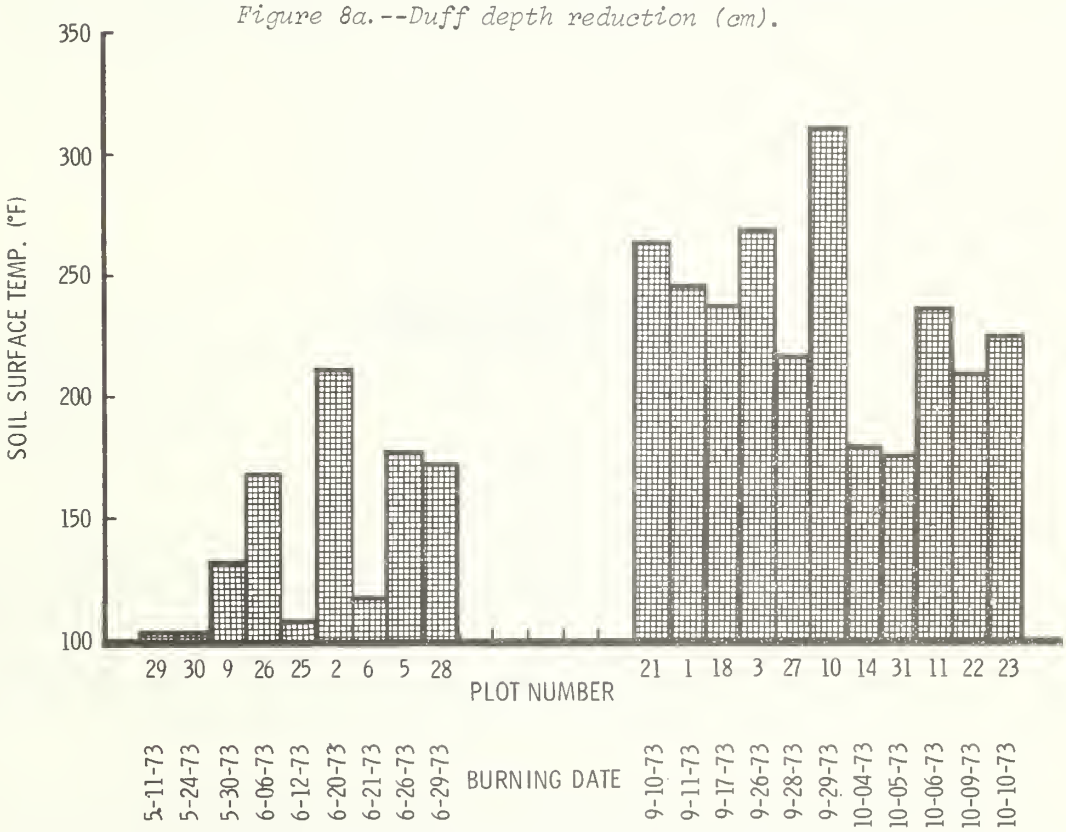

Figure 8b.--Average temperature reached at mineral soil surface (103°F was lowest temperature that could be recorded).

DATA COLLECTION AND ANALYSIS

Shrub data used in this study were collected on twenty-six 1-m^2 quadrats within each burn plot. Two quadrats were randomly located about each of the 13 fuel inventory points. Shrub stems were tallied by species and stem size class before, and 1 and 2 years after the prescribed fires. A fire-pruned stem was considered to be one plant if it was alive at ground level. Sprouts originating from below the duff or soil level were considered to be separate plants.

Regression analysis was used to relate numbers of *Vaccinium globulare* present in all shrub inventory quadrats 1 and 2 years after fire to fuel, environmental, and fire effects variables and to prefire *Vaccinium* numbers. Computer program REX (Grosenbaugh 1967) was used to evaluate model alternatives. Two different sets of independent variables were used. One set contained variables that described fuel, moisture, and environmental conditions at the time of plot ignition. The second set contained variables that measured fire effects such as fuel reduction and duff and soil heating. Equations were developed for all 20 fires, and for spring and fall fires separately. A complete description of statistical procedures can be found in Miller (1976). Variable mean values, ranges, and standard deviations are listed in appendix 1.

RESULTS

Variability of Fire Effects

Because foliage of *Vaccinium* globulare is very nonflammable, plants are consumed by fire only after being dried and preheated by burning woody fuels (Rodney A. Norum personal communication 1976, Northern Forest Fire Laboratory). Dense stand of *Vaccinium* in large forest openings on the Lubrecht site did not burn because fuels were not present. Great heat input to the stem rhizome complex occurred in the vicinity of large amounts of dry fuel. Fire treatment was never uniform across a plot area because of fuel discontinuity.

The distribution of aboveground stems of *Vaccinium globulare* prior to fire treatment varied greatly among plots and among microsites on the same plot (table 1). Fire created a mosaic of effects, greatly increasing the variability already present. Plant response differed between microsites, with numbers increasing, decreasing, or changing very little. The percentage of plot area that fell into each of these classes ranged widely between plots burned in the spring and fall and between some plots burned within the same season.

Table 1.--*Plot summaries for* Vaccinium globulare

Plot No.	Average number of stems per square meter: Before fire: 1973	1 year after fire: 1974	2 years after fire: 1975	Number of quadrats out of 26 with plants: Before fire: 1973	1 year after fire: 1974	2 years after fire: 1975	Percent change in number of stems: 1973-1974	1973-1975
				SPRING FIRES				
29	49.54	61.62	66.23	26	26	26	24.38	33.69
30	28.15	39.65	50.58	25	26	26	40.85	79.68
9	23.08	28.77	39.08	21	25	25	24.65	69.32
26	45.77	62.85	83.27	26	26	26	37.30	81.93
25	43.08	46.65	53.85	25	24	25	8.29	25.00
2	3.35	35.50	23.08	11	18	16	959.70	589.96
6	18.54	32.15	40.69	21	22	24	73.41	119.47
5	27.38	39.00	47.58	24	25	21	42.44	73.78
28	30.19	35.46	39.88	26	18	19	17.46	32.10
				FALL FIRES				
21	16.85	5.69	14.35	22	7	17	-66.23	-14.84
1	3.96	2.31	2.08	8	4	7	-41.67	-47.47
18	33.19	29.85	33.81	23	15	19	-10.06	1.87
3	7.50	5.19	8.35	6	7	7	-3.08	11.33
27	18.73	37.54	46.62	25	18	20	100.43	148.91
10	34.65	38.08	47.35	26	22	23	9.90	36.65
14	97.96	92.96	117.54	26	26	26	-5.10	19.99
31	26.08	26.31	49.73	25	23	24	0.88	90.68
11	16.42	23.88	31.58	23	23	24	45.43	92.33
22	12.42	4.54	11.46	21	9	13	-63.45	-7.73
23	15.73	38.00	42.31	25	16	19	141.58	168.98

The number of *Vaccinium* stems present 1 full year after spring fires was always greater than before fire. New plants continued to appear in the second year (table 1). Sprouts sometimes appeared on quadrats where no aboveground stems existed before fire. These plants may have appeared from rhizomes that had not previously supported stems on those quadrats, or from rhizome tips that grew toward the surface. Only one spring fire removed plants from some quadrats for at least 2 years--the last fire, ignited on June 29, 1973.

At the end of the first growing season, *Vaccinium* numbers were less than before fire on 6 of the 11 fall burn plots. Little or no sprouting occurred on many quadrats. *Vaccinium* stems appeared in some of these quadrats the second growing season. Sprouts came from deeper levels, and sometimes may have originated from new or stimulated rhizome tips. Increases in plant numbers over prefire totals occurred on eight of the fall plots by the end of the second year (table 1). *Vaccinium* stem numbers did increase on some fall-burned plots, because plant density increased on some quadrats. However, all rhizomes were often killed on other areas of these same plots (fig. 9).

The depth of heat penetration controlled the number of sprouts that appeared. If a plant was burned off above ground level, several new shoots appeared as branches on one plant (fig. 10). Sprouts that appeared from laterally growing rhizomes functioned as separate plants (fig. 11). Greatly increased plant numbers resulted if stems were killed back below ground level and sprouts appeared from rhizomes (fig. 12). If heat penetrated to deeper levels with fewer rhizomes, sprout density was low (fig. 13).

Figure 9a.--Heavy preburn fuel loading.

Figure 9b.--Same site shortly after fire.

Figure 9c.--Abundant Epilobium angustifolium *and* Calamagrostis rubescens *regeneration 2 years later. Few* Vaccinium *sprouts were present.*

Figure 10.--Outgrowing buds form branches on partially killed stem.

Figure 11.--Stems killed back to ground level. Sprouts appear from rhizomes.

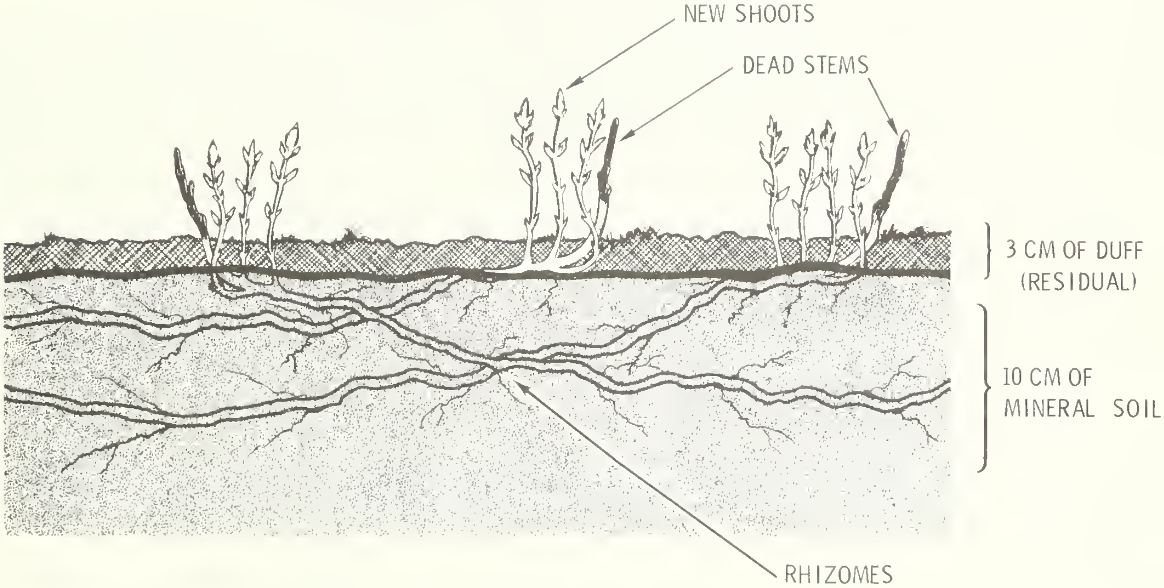

Figure 12.--Increased plant density resulted from heat penetration to slightly below the ground surface.

Figure 13.--Most rhizomes were killed on this deeply heated site. A few sprouts originated from rhizomes up to 22 cm below this surface. Some sprouts took longer than one growing season to appear.

Factors Related to Sprouting

Regression equations identified factors that could account for observed differences in *Vaccinium* response to fire. Many significant equations containing many different variables were developed from each independent variable set for each time period. The variables that appeared in the four most significant equations for the 9 spring fires and for the 11 fall fires and the R^2 values of these eight equations are listed in tables 2 and 3. All of these independent variables were significant to at least the 0.05 probability level. The high statistical significance suggests that a strong relationship exists between these factors and the postfire *Vaccinium* community. Full statistics for these equations can be found in appendix 2.

Variables appearing in these equations were related to fire characteristics. Fuel loading and depth established the potential for heat release. Fuel moisture determined the degree of fuel ignitibility. Slope acted as wind, affecting fire spread. Relative humidity and ambient air temperature regulate moisture of very fine fuels, particularly when these fuels are dry (Steen 1963). Rhizome heating was limited by soil and lower duff moisture. Aspects of the heat regime created by fire are directly or indirectly measured by mean duff depth reduction, percent brush weight reduction, 1- to 3-inch fuel reduction, fire intensity, and mineral soil surface temperature.

Other variables appeared in other, slightly less significant equations. Preburn fuel loadings or fuel reduction in all other size classes, 0.635 to 2.54 cm (1/4 to 1 inch) diameter fuel moisture content, windspeed, and temperatures attained at and below the duff surface were all significant to at least the 0.05 probability level in equations for both spring and fall fires.

Table 2.--*Variables present in most significant regression equations for 9 spring and 11 fall fires*

Y	Preburn number of stems	0 to 0.635 cm preburn fuel weight	Rotten 7.62 cm larger, preburn fuel weight	Total 7.62 cm and larger preburn fuel weight	Dead fuel depth	Slope	0 to 0.635 cm fuel moisture content	Moisture content of lower duff	Soil moisture content	Relative humidity	Ambient air temperature/soil moisture content	R^2
Number of *Vaccinium* stems 1 year after spring fires			X							X	X	0.8700
Number of *Vaccinium* stems 2 years after spring fires			X						X	X		.9170
Number of *Vaccinium* stems 1 year after fall fires	X	X		X	X							.9812
Number of *Vaccinium* stems 2 years after fall fires	X					X	X	X				.9821

Table 3.--*Variables present in most significant regression equations for 9 spring and 11 fall fires*

Y	Preburn number of stems	Fire intensity	2.54 to 7.62 cm fuel weight reduction	Duff depth reduction	Percent shrub weight reduction	Average temperature at mineral soil surface	Adjusted* temperature at mineral soil surface	Soil moisture content	R^2
Number of *Vaccinium* stems 1 year after spring fires	X	X		X					0.9474
Number of *Vaccinium* stems 2 years after spring fires	X	X			X				.9535
Number of *Vaccinium* stems 1 year after fall fires	X		X			X		X	.9692
Number of *Vaccinium* stems 2 years after fall fires	X		X				X	X	.9817

$$* \quad \Sigma \frac{\text{Temperature registered on each soil temperature plate}}{\text{13 plates/plot}} \times \begin{array}{c}\text{percentage of points}\\ \text{heated at the mineral}\\ \text{soil surface}\end{array}$$

Certain variables only occurred in equations for spring fires. Foliar moisture content may have inhibited fuel ignition when vegetation was fairly lush, but not in the fall when vegetative moisture content levels were considerably lower. Relative humidity and ambient air temperature may have been important in the spring because dry fine fuels were very sensitive to atmospheric humidity changes. Average fire intensity (as computed from crown scorch height) measured a characteristic of spring fires that was closely related to postfire *Vaccinium* numbers.

DISCUSSION OF RESULTS

The number of *Vaccinium* stems present after prescribed fire was more closely related to the number of stems present before fire treatment than to any other single factor. The more stems that protruded through duff and soil layers, the more sites were readily available for pruning by fire, and the more stems were likely to be replaced by one or several sprouts. High stem density before fire may have been associated with a denser rhizome network, increasing the probability that some new stems would be initiated from rhizomes which had not previously supported aboveground stems. All seasonal differences in sprouting were caused by differences in heat penetration at different times of the year. The number of buds stimulated to grow on each pruned stem or rhizome did not vary with season. The only seasonal response difference was that plants burned in the fall did not produce sprouts from released buds until the following spring.

The fairly consistent increases in *Vaccinium* numbers on most of the area of plots burned in the spring and the rhizome mortality which occurred on many fall fire plots were caused by differences in fuel loading and distribution, burning conditions, and duff and soil moisture levels. In the spring season, most fire heat came from consumption of fuels in smaller size classes. Large, sound fuels were too wet to burn. Large, rotten fuels were sometimes consumed by glowing combustion and some dry upper duff layers were removed. Lower duff and soil were wet enough to protect most rhizomes. In the fall, large fuels were dry enough to burn. Enough heat was released to dry and consume large amounts of duff. Soil moisture levels were too low to prevent soil heating and rhizome death. The importance of duff and soil moisture is emphasized by the fact that the only spring fire with rhizome mortality was ignited when duff and soil moisture content were very low.

A fire treatment most beneficial to *Vaccinium globulare* will remove senescent stems but cause minimal rhizome damage. Plants will be killed back to ground level if only fine fuels are consumed and lower duff and soil moisture content are high. The number of *Vaccinium* stems on three spring fire plots (plots 6, 26, and 30) increased from 80 to 120 percent over prefire totals. Conditions were dry enough for fire to carry, but not so dry that fire heat damaged rhizomes. Increases were not as great after other spring fires because fuels were too wet or duff and soil were too dry. One spring fire, ignited when conditions were fairly dry, caused a 900 percent increase in *Vaccinium* numbers in the first year after fire. However, this response may have been atypical because one-third of these plants died by the next year.

Fire will remove *Vaccinium globulare* from quadrats where heat from intensely burning fuels and duff reaches below the depth of all rhizomes. This occurred on many quadrats during fall fires, although sprouting was quite prolific on other quadrats not so deeply heated. *Vaccinium* was present on 35 to 68 percent fewer quadrats the first year after four fall fires (plots 1, 18, 21, and 22). After 2 years, plant numbers had not attained prefire totals on three of these plots. Fine fuels were too wet to be ignited on plot 18 (20.3 percent moisture content) but large fuels were dry enough to burn without small fuel combustion. Much rhizome death resulted from high duff consumption on plot 1, although it had a very light fuel loading (1.4 kg/m^2, about 6.4 tons/acre) because fine fuels, duff, and soil were extremely dry when the plot was ignited. Fall fires conducted in areas with very light fuel loadings when duff and fine fuels are wet will rarely kill rhizomes. *Vaccinium* was present on the same number of quadrats after a fall fire on a plot with a fuel loading of about 2.8 kg/m^2 (12.5 tons/acre) and a dense stand of *Vaccinium* plants. However, there was not enough fuel to carry fire and many plants were not pruned.

Moisture levels that favored or inhibited *Vaccinium* regeneration at the Lubrecht site are summarized in the following tabulation:

	Promotion (Percent)	*Inhibition (Percent)*
0 to 0.635 cm fuel moisture content	< 12	< 19
Upper duff moisture content	> 25	< 70
Lower duff moisture content	> 100	< 70
Soil moisture content	> 30	< 19
Large fuel moisture	high--(will not burn, or difficult to ignite.)	low--(will burn, easy to ignite.)

Heat may not penetrate soil if soil moisture content is above a certain critical level. These results should be verified on other mesic sites with *Vaccinium*. Similar moisture levels may control the response of other rhizomatous species such as *Spiraea betulifolia* and *Symphoricarpos albus*.

Fire response of root crown sprouting shrubs such as menziesia (*Menziesia ferruginea*) and serviceberry (*Amelanchier alnifolia*) may be quite different from *Vaccinium* because of differences in the form, size, and location of sprouting sites. Also, it is not known whether these species have dormant buds or initiate new buds in response to fire pruning. There is a need to explore the relationship between fire intensity and postfire sprouting of these species and those of other forest types.

RECOMMENDATIONS

Spring burning is recommended to increase the density of *Vaccinium globulare* in Douglas-fir/western larch. Most spring fires will increase *Vaccinium* numbers on at least part of the burned area. Fires should not be conducted if lower duff and soil are dry.

If decreased *V. globulare* density is desired, burning should be done in the fall. Fire will usually kill rhizomes beneath fuel concentrations. Burning conditions which cause large amounts of duff reduction will result in the greatest decreases in *Vaccinium* numbers.

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APPENDIX

APPENDIX 1a. — Mean and Standard Deviation of Measured Variables

	Variable	Spring fires Mean	Spring fires Standard deviation	Fall fires Mean	Fall fires Standard deviation
1.	Number of *Vaccinium globulare* stems before fire (1973)	777.33	379.16	670.09	670.51
2.	Preburn shrub weight (kg/m^2)	.13	.07	.07	.04
3.	0 to 1/4 inch (0 to 0.635 cm) preburn fuel weight (kg/m^2)	.07	.01	.10	.03
4.	1/4 to 1 inch (0.635 to 2.54 cm) preburn fuel weight (kg/m^2)	.14	.04	.15	.09
5.	1 to 3 inch (2.54 to 7.62 cm) preburn fuel weight (kg/m^2)	.43	.21	.57	.31
6.	Rotten, 3 inch (7.62 cm) and larger preburn fuel weight (kg/m^2)	5.84	3.04	4.10	2.18
7.	Sound, 3 inch (7.62 cm) and larger preburn fuel weight (kg/m^2)	1.11	1.20	.65	.98
8.	Total, 3 inch (7.62 cm) and larger preburn fuel weight (kg/m^2)	6.95	2.82	4.75	2.76
9.	Total preburn fuel weight (kg/m^2)	7.59	2.79	5.57	2.80
10.	Preburn duff depth (cm)	7.24	1.20	7.05	1.83
11.	Preburn herbaceous vegetation weight (kg/m^2)	.09	.06	.07	.03
12.	Preburn dead fuel depth (cm)	16.59	8.68	16.15	8.63
13.	Windspeed (mph)	2.56	3.09	2.64	2.66
14.	Average slope (percent)	35.00	8.00	37.00	10.00
15.	0 to 1/4 inch (0 to 0.635 cm) fuel moisture content (percent)	10.74	2.02	20.38	6.33
16.	1/4 to 1 inch (0.635 to 2.54 cm) fuel moisture content (percent)	11.46	3.05	23.24	8.22
17.	0 to 1/4 inch (0 to 0.635 cm) fuel weight reduction (kg/m^2)	.02	.02	.04	.03
18.	1/4 to 1 inch (0.635 to 2.54 cm) fuel weight reduction (kg/m^2)	.06	.05	.08	.09
19.	0 to 1 inch (0 to 2.54 cm) fuel weight reduction (kg/m^2)	.09	.05	.12	.11
20.	1 to 3 inch (2.54 to 7.62 cm) fuel weight reduction (kg/m^2)	.08	.23	.28	.32
21.	Total, 3 inch (7.62 cm) and larger fuel weight reduction (kg/m^2)	4.38	3.11	3.36	2.75
22.	Total fuel weight reduction (kg/m^2)	4.55	3.14	3.83	2.70
23.	Mean duff depth reduction (cm)	1.74	.49	3.85	1.74
24.	Percent duff depth reduction (percent)	24.41	6.41	53.41	14.51
25.	Fire intensity (kcal/sec/m^2)	103.07	63.01	71.68	44.84
26.	Shrub weight reduction (percent)	64.47	20.95	53.92	20.91
27.	Average mineral soil surface temperature (°F)	143.56	39.39	232.73	39.36
28.	Adjusted soil surface temperature (°F)	60.56	50.98	174.36	56.83
29.	Average duff surface temperature (°F)	252.44	62.19	359.27	66.42
30.	Adjusted duff surface temperature (°F)	220.00	81.38	338.00	74.89
31.	Average temperature at 2.5 cm below duff surface (°F)	191.00	56.39	320.27	78.05
32.	Average temperature at 5.0 cm below duff surface (°F)	163.89	48.89	299.27	76.21
33.	Average temperature at 7.5 cm below duff surface (°F)	141.78	31.98	263.91	79.25
34.	Upper duff moisture content (percent)	40.57	21.45	70.53	28.86
35.	Lower duff moisture content (percent)	89.99	42.84	79.11	23.02
36.	Soil moisture content (percent)	29.09	11.33	12.51	3.97
37.	Relative humidity (percent)	37.44	7.78	39.45	7.98
38.	Understory foliage moisture content (percent)	259.00	57.46	128.31	16.67
39.	Ambient air temperature (°F)	68.56	6.09	59.91	11.09
40.	Ambient air temperature/soil moisture content	2.80	1.34	5.38	2.74
41.	Number of *Vaccinium globulare* stems 1 year after fire (1974)	1,102.56	319.89	719.36	676.14
42.	Number of *Vaccinium globulare* stems 2 years after fire (1975)	1,283.33	452.27	955.27	826.41

APPENDIX 1b. — Range of Measured Variables

Variable	Spring fires Low	Spring fires High	Fall fires Low	Fall fires High
1. Number of *Vaccinium globulare* stems before fire (1973)	87.00	1,288.00	103.00	2,547.00
2. Preburn shrub weight (kg/m^2)	.07	.27	.03	.18
3. 0 to 1/4 inch (0 to 0.635 cm) preburn fuel weight (kg/m^2)	.05	.09	.05	.15
4. 1/4 to 1 inch (0.635 to 2.54 cm) preburn fuel weight (kg/m^2)	.08	.20	.05	.36
5. 1 to 3 inch (2.54 to 7.62 cm) preburn fuel weight (kg/m^2)	.14	.76	.20	1.24
6 Rotten, 3 inch (7.62 cm) and larger preburn fuel weight (kg/m^2)	1.62	10.52	1.01	7.31
7. Sound, 3 inch (7.62 cm) and larger preburn fuel weight (kg/m^2)	.00	3.56	.00	3.44
8. Total, 3 inch (7.62 cm) and larger preburn fuel weight (kg/m^2)	2.14	10.52	1.08	10.75
9. Total preburn fuel weight (kg/m^2)	3.01	11.06	1.41	11.41
10. Preburn duff depth (cm)	5.00	8.40	4.30	10.80
11. Preburn herbaceous vegetation weight (kg/m^2)	.04	.25	.03	.14
12. Preburn dead fuel depth (cm)	3.62	28.50	6.97	30.31
13. Windspeed (mph)	.00	10.00	.00	7.00
14. Average slope (percent)	21.00	48.00	23.00	50.00
15. 0 to 1/4 inch (0 to 0.635 cm) fuel moisture content (percent)	8.60	15.46	8.03	35.20
16. 1/4 to 1 inch (0.635 to 2.54 cm) fuel moisture content (percent)	8.58	18.92	8.40	42.50
17. 0 to 1/4 inch (0 to 0.635 cm) fuel weight reduction (kg/m^2)	-.02	.06	-.02	.08
18. 1/4 to 1 inch (0.635 to 2.54 cm) fuel weight reduction (kg/m^2)	-.03	.12	-.0002	.31
19. 0 to 1 inch (0.635 to 2.54 cm) fuel weight reduction (kg/m^2)	.04	.18	-.002	.38
20. 1 to 3 inch (2.54 to 7.62 cm) fuel weight reduction (kg/m^2)	-.36	.42	-.02	1.05
21. Total, 3 inch (7.62 cm) and larger fuel weight reduction (kg/m^2)	.71	8.84	-1.06	9.21
22. Total fuel weight reduction (kg/m^2)	.72	9.01	-1.01	9.27
23. Mean duff depth reduction (cm)	1.20	2.70	1.60	7.60
24. Percent duff depth reduction (percent)	14.30	34.60	23.50	71.80
25. Fire intensity ($kcal/sec/m^2$)	33.66	213.76	34.70	159.57
26. Shrub weight reduction (percent)	36.59	95.44	17.91	85.55
27. Average mineral soil surface temperature (°F)	103.00	211.00	175.00	310.00
28. Adjusted soil surface temperature (°F)	8.00	148.00	50.00	262.00
29. Average duff surface temperature (°F)	132.00	346.00	274.00	494.00
30. Adjusted duff surface temperature (°F)	53.00	338.00	238.00	494.00
31. Average temperature at 2.5 cm below duff surface (°F)	107.00	275.00	209.00	466.00
32. Average temperature at 5.0 cm below duff surface (°F)	103.00	243.00	198.00	442.00
33. Average temperature at 7.5 cm below duff surface (°F)	103.00	186.00	191.00	432.00
34. Upper duff moisture content (percent)	12.98	70.30	9.77	115.40
35. Lower duff moisture content (percent)	18.89	145.06	22.78	103.19
36. Soil moisture content (percent)	14.20	43.26	5.74	18.41
37. Relative humidity (percent)	27.00	52.00	28.00	53.00
38. Understory foliage moisture content (percent)	139.88	343.30	91.51	157.67
39. Ambient air temperature (°F)	55.00	75.00	44.00	77.00
40. Ambient air temperature/soil moisture content	1.38	5.14	2.62	13.07
41. Number of *Vaccinium globulare* stems 1 year after fire (1974)	923.00	1,634.00	60.00	2,417.00
42. Number of *Vaccinium globulare* stems 2 years after fire (1975)	600.00	2,165.00	54.00	3,056.00

APPENDIX 2. — Full Statistics for Regression Equations

Equation 1: Spring 1974

$$Y(1) = 1104.2278 - 172.7340\ X(6) + 5619.8914\ X(37) - 392.1480\ X(40)$$

Variable	*Description*	*Range*	*"t"*	*Level of significance*
Y(1)	Number of *Vaccinium* stems present 1 year after spring fires	923 to 1,634		
X(6)	Rotten, 7.62 cm (3 in) and larger, preburn fuel weight (kg/m^2)	1.62 to 10.52	5.1640	0.01
X(37)	Relative humidity (percent)	27 to 52	4.6770	.01
X(40)	Ambient air temperature/ Soil moisture content	1.38 to 5.14	5.7060	.01

$R^2 = 0.8700$

Standard error of the estimation = 145.8893

Source of variation	*df*	*SS*	*MS*	*F*
Due to regression	3	712221.740	237407.247	11.1544
Error	5	106418.480	21283.696	
Total	8	818640.220		

Since $F_{0.025}$ with 3/5 df is 7.76, the regression is deemed significant at the 0.025 level.

Equation 2: Spring 1975

$$Y(2) = -2403.5965 - 219.0046\ X(6) + 66.7587\ X(36) + 8116.4752\ X(37)$$

Variable	*Description*	*Range*	*"t"*	*Level of significance*
Y(2)	Number of *Vaccinium* stems present 2 years after spring fires	600 to 2,165		
X(6)	Rotten, 7.62 cm (3 in) and larger, preburn fuel weight (kg/m^2)	1.62 to 10.52	5.9220	0.01
X(36)	Soil moisture content (percent)	14.20 to 43.26	7.3990	.001
X(37)	Relative humidity (percent)	27 to 52	5.9692	.01

$R^2 = 0.9170$

Standard error of the estimation = 171.7840

Source of variation	*df*	*SS*	*MS*	*F*
Due to regression	3	1630219.200	543406.400	18.4145
Error	5	147548.770	29509.755	
Total	8	1777768.990		

Since $F_{0.005}$ with 3/5 df is 16.53, the regression is deemed significant at the 0.005 level.

Equation 3: Fall 1974

$$Y(3) = -498.3475 + 1.0430\ X(1) + 6754.6459\ X(3) + 70.3139\ X(8) - 28.5512\ X(12)$$

Variable	*Description*	*Range*	*"t"*	*Level of significance*
Y(3)	Number of *Vaccinium* stems present 1 year after fall fires	60 to 2,417		
X(1)	Preburn number of *Vaccinium* stems	103 to 2,547	16.1883	0.001
X(3)	0 to 0.635 cm (0 to 1/4 in) preburn fuel weight (kg/m^2)	0.05 to 0.15	4.0535	.01
X(8)	Total, 7.62 cm (3 in) and larger preburn fuel weight (kg/m^2)	1.08 to 10.75	4.2065	.01
X(12)	Dead fuel depth (cm)	6.97 to 30.31	4.8142	.01

$R^2 = 0.9812$

Standard error of the estimation = 119.5520

Source of variation	*df*	*SS*	*MS*	*F*
Due to regression	4	4485954.500	1121488.625	78.4659
Error	6	85756.090	14292.682	
Total	10	4571710.590		

Since $F_{0.001}$ with 4/6 df is 21.92, the regression is deemed significant at the 0.001 level.

Equation 4: Fall 1975

$$Y(4) = 442.0076 + 1.0742\ X(1) - 1520.2378\ X(14) - 31.5622\ X(15) + 12.7059\ X(35)$$

Variable	*Description*	*Range*	*"t"*	*Level of significance*
Y(4)	Number of *Vaccinium* stems present 2 years after fall fires	54 to 3,056		
X(1)	Preburn number of *Vaccinium* stems	103 to 2,547	13.9059	0.001
X(14)	Average slope (percent)	23 to 50	2.8921	.05
X(15)	0 to 0.635 cm (0 to 1/4 in) fuel moisture content (percent)	8.03 to 35.20	3.3537	.02
X(35)	Moisture content of lower duff (percent)	22.78 to 103.19	4.5044	.01

$R^2 = 0.9821$

Standard error of the estimation = 142.6204

Source of variation	*df*	*SS*	*MS*	*F*
Due to regression	4	6707512.600	1676878.150	82.4400
Error	6	122043.540	20340.591	
Total	10	6829556.140		

Since $F_{0.001}$ with 4/6 df is 21.92, the regression is deemed significant at the 0.001 level.

Equation 5: Spring 1974

$$Y(1) = 1173.3210 + 0.6756\ X(1) - 451.6954\ X(23) + 1.8632\ X(25)$$

Variable	*Description*	*Range*	*"t"*	*Level of significance*
Y(1)	Number of *Vaccinium* stems present 1 year after spring fires	923 to 1,634		
X(1)	Preburn number of *Vaccinium* stems	87 to 1,288	7.4264	0.001
X(23)	Duff depth reduction (cm)	1.2 to 2.7	5.2239	.01
X(25)	Fire intensity ($kcal/sec/m^2$)	33.66 to 213.76	2.6770	.05

$R^2 = 0.9474$

Standard error of the estimation = 92.8019

Source of variation	*df*	*SS*	*MS*	*F*
Due to regression	3	775579.230	258526.410	30.0186
Error	5	43060.990	8612.198	
Total	8	818640.220		

Since $F_{0.005}$ with 3/5 df is 16.53, the regression is deemed significant at the 0.005 level.

Equation 6: Spring 1975

$$Y(2) = 555.6506 + 1.4142\ X(1) + 3.6020\ X(25) - 11.2802\ X(26)$$

Variable	*Description*	*Range*	*"t"*	*Level of significance*
Y(2)	Number of *Vaccinium* stems present 2 years after spring fires	600 to 2,165		
X(1)	Preburn number of *Vaccinium* stems	87 to 1,288	9.9368	0.001
X(25)	Fire intensity (kcal/sec/m^2)	33.66 to 213.76	3.4798	.02
X(26)	Percent shrub weight reduction	36.59 to 95.44	3.7456	.02

$R^2 = 0.9535$

Standard error of the estimation = 128.2812

Source of variation	*df*	*SS*	*MS*	*F*
Due to regression	3	1695037.600	565012.533	34.1478
Error	5	82730.384	16546.077	
Total	8	1777767.984		

Since $F_{0.001}$ with 3/5 df is 33.20, the regression is deemed significant at the 0.001 level.

Equation 7: Fall 1974

$$Y(3) = 807.9676 + 0.7183\ X(1) - 885.4242\ X(20) - 4.8737\ X(27) + 67.7194\ X(36)$$

Variable	*Description*	*Range*	*"t"*	*Level of significance*
Y(3)	Number of *Vaccinium* stems present 1 year after fall fires	60 to 2,417		
X(1)	Preburn number of *Vaccinium* stems	103 to 2,547	8.2441	0.001
X(20)	2.54 to 7.62 cm (1 to 3 in) fuel weight reduction (kg/m^2)	-0.02 to 1.05	4.7649	.01
X(27)	Average temperature at mineral soil surface (°F)	175 to 310	2.9972	.05
X(36)	Soil moisture content (percent)	5.74 to 18.41	3.8224	.01

$R^2 = 0.9692$

Standard error of the estimation = 153.0757

Source of variation	*df*	*SS*	*MS*	*F*
Due to regression	4	4431117.500	1107779.375	47.2760
Error	6	140593.080	23432.181	
Total	10	4571710.580		

Since $F_{0.001}$ with 4/6 df is 21.92, the regression is deemed significant at the 0.001 level.

Equation 8: Fall 1975

$$Y(4) = 605.4407 + 0.9297\ X(1) - 774.6745\ X(20) - 4.6911\ X(28) + 60.7141\ X(36)$$

Variable	*Description*	*Range*	*"t"*	*Level of significance*
Y(4)	Number of *Vaccinium* stems present 2 years after fall fires	54 to 3,056		
X(1)	Preburn number of *Vaccinium* stems	103 to 2,547	12.0059	0.001
X(20)	2.54 to 7.62 cm (1 to 3 in) fuel weight reduction (kg/m^2)	-0.02 to 1.05	4.5531	.01
X(28)	Adjusted mineral soil surface temperature	50 to 262	4.9959	.01
X(36)	Soil moisture content (percent)	5.74 to 18.41	4.2349	.01

$R^2 = 0.9817$

Standard error of the estimation = 144.4982

Source of variation	*df*	*SS*	*MS*	*F*
Due to regression	4	6704277.800	1676069.450	80.2725
Error	6	125278.410	20879.734	
Total	10	6829556.210		

Since $F_{0.001}$ with 4/6 df is 31.09, the regression is deemed significant at the 0.001 level.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1977-0-777-023-11

Miller, Melanie
1977. Response of blue huckleberry to prescribed fires in a western Montana larch-fir forest. USDA For. Serv. Res. Pap. INT-188, 33 p. Intermountain Forest and Range Experiment Station, Ogden, Utah 84401.

In a western larch/Douglas-fir forest type in western Montana, 9 spring and 11 fall understory burns were conducted. The number of Vaccinium globulare (blue huckleberry) stems present before burning and 1 and 2 years after burning were related to fuel loadings, moisture content of fuel, duff and soil, environmental conditions, fuel reduction, fire intensity, and temperatures reached at the duff and soil surface during the fires. Because moist duff and soil protected rhizomes from fire heat, increases in plant numbers always resulted from spring fires. The large amounts of heat released by fall fires caused rhizome mortality on plots where levels of duff and soil moisture were low.

KEYWORDS: fire regeneration; fire effects; shrub response, larch-fir forest

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Headquarters for the Intermountain Forest and Range Experiment Station are in Ogden, Utah. Field programs and research work units are maintained in:

- Billings, Montana
- Boise, Idaho
- Bozeman, Montana (in cooperation with Montana State University)
- Logan, Utah (in cooperation with Utah State University)
- Missoula, Montana (in cooperation with University of Montana)
- Moscow, Idaho (in cooperation with the University of Idaho)
- Provo, Utah (in cooperation with Brigham Young University)
- Reno, Nevada (in cooperation with the University of Nevada)